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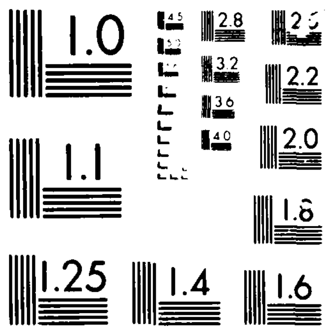

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When we began our study of inverse procedures to determine ocean circulation, our intent was to build on past studies by other scientists, i.e., to find useful extensions of proven methods. It turned out, however, that much of the work that preceded ours contained elements that were unclear so we were forced to start from the beginning and to establish reliable and reproducible procedures.

Our starting point was to accept the problem that Wunsch (1978) had posed and to sort out the methodology for solving it. As it happens, we were able to derive an empirical search procedure that led to a level of no motion without requiring the mathematical apparatus of inverse theory. We obtained results for two data sets, one from the Tasman-Coral seas (Fiadeiro and Veronis, 1982; hereafter FV2) and one from the Bermuda Triangle (Fiadeiro and Veronis, 1983; hereafter FV3). The latter required an inverse correction to satisfy mass conservation for the upper two layers of the region. We also developed a new procedure for obtaining an inverse correction taking into account the noise of the data.

Since then several data sets that appeared at the outset to be appropriate for an inverse study have been examined. The first was the set of stations that enclose the portion of the western North Atlantic from 55°W to the N.A. coast. This 55°W data set had been analyzed by Luyten and Stommel (1982) who had to make what appeared to be <u>ad hoc</u> assumptions in order to obtain

results. A plot of the data revealed the difficulties that they had had to face. The T and S distributions are so variable and there are so many different water masses along that section that an analysis based on conservative properties is simply not feasible. We put that data set aside with an intention to return to it when procedures have been developed that are more appropriate for such non-conservative distributions.

In the meantime we examined a grid network of observations in the Coral Sea obtained by Carl Nilsson of CSIRO, Australia. The dense network was potentially of great use because it would allow calculations of differences of tracers and a number of independent checks on the methodology. However, the salinities were so unreliable and scattered that that data set was discarded. A similar fate fell on a grid network of stations gathered by Nowlin and his collegues at Texas A&M. There were too few deep stations to admit a meaningful use of the network. However, it is possible to carry out at least a preliminary exploration by using a section from the Yucatan Peninsula to the west coast of Florida. The closed box lies between the section and the Gulf Coast. Eileen Hoffman at Texas A&M has started on a calculation intending to apply our empirical search procedure to that closed box region. We have outlined the procedure for her and intend to keep in touch with her providing help when necessary.

Another data set that looked promising came from the Oceanus 78 cruise of Armi and Stommel (1983) in the beta-triangle area of the eastern subtropical North Atlantic. We have put that system onto our computer and have carried out an empirical search

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procedure for the level of no motion. The result is that any reference level from about 1200 m to the bottom can serve as a level of no motion. The region is not large and is enclosed by station data. Apparently, conservation of mass does not constrain the system sufficiently to lead to definitive results.

It seems to us that the lack of significant constraints ~~is~~ characteristic of most oceanographic data sets, This is not so surprising since they were not gathered for the purpose of making the type of study that we have undertaken. In most cases a traditional analysis with all ~~of~~ its inaccuracies, assumptions and uncertainties provides as much information as one can obtain. We have decided that there is little point in writing up the results of a quantitative analysis that is not more conclusive than the traditional approach. Unfortunately, it is difficult to determine how conclusive the results are without a full treatment of the data so it is nearly as time-consuming to obtain a negative result as a positive one.

Our studies have indicated the need for additional considerations to constrain the system more effectively, For that reason we have also formulated the problem of trying to determine the velocity field from tracer distributions. In order to determine how effective such an approach is, we first analyzed a simple, direct system in which a known velocity field together with given boundary conditions on the tracers was used to determine consistent tracer distributions. The problem was then inverted for a subportion of the original system, i.e., the known tracer distributions were used to obtain the velocity field, and

the calculated velocity was compared with the given one in various subregions of the original problem. This effort was reported in detail in Fiadeiro and Veronis (1984). A brief summary of the results is given here.

A single tracer does not contain enough information to determine the flow in a two-dimensional field. The problem is underdetermined (more unknowns than equaticns). This conclusion has important implications for the type of inverse study that has been used for the determination of absolute velocities in the ocean (Wunsch, 1977, 1978; Roemmich, 1979; Fu, 1981; Wunsch and Grant, 1982; FV2 and FV3). Those inverse calculations are all based on underdetermined systems and the results must be subject to the same criticism. We had come to the same conclusion in Stommel and Veronis (1981), FV2, and FV3, but at the time we did not have the direct comparison between real and calculated velocity that the present study makes possible.

Two tracers yield the correct velocity. In this case, even when truncation error is present (always true with observed data) an acceptable approximation to the correct velocity can be obtained. When a single tracer is used together with qualitatively correct velocity information (based on intuitively plausible estimates), an acceptable velocity also emerges. We have proposed a criterion that serves as an indicator that the calculated velocity is close to the real one. Through the use of weights, we have also shown that the system will retain correct *a priori* information and discard inconsistent *a priori* information.

Though the foregoing conclusions are based on a model using simulated data, the results apply to real systems, as well. The

fabricated data provided us with correct values against which the calculated results could be tested, a possibility that does not exist with real data. However, the criteria that we established are applicable to real data and should provide a useful (and hitherto, unavailable) measure of the correctness of the calculated results.

Obtaining a grid of tracer data appropriate for such an inverse study is costly both in time and money. It is unlikely that a useful data set will simply emerge from an oceanographic observational program designed for some other purpose. However, there are groups involved in coastal studies where the geographical area is much more limited and a dense grid of stations is feasible.

One such group is in the Civil Engineering Department at the University of Western Australia. Professor Jorg Imberger has been making observations in the Wellington Reservoir, an estuary north of Perth in Western Australia. His data arrays are already pertinent for an inverse study and he has also developed a program for estimating the vertical mixing coefficients from vertical arrays of stations.

During a six-week visit there, Veronis helped them to set up a program for estimating the velocities from T and S measurements. A report on this effort is being prepared for publication in JGR. The long-range plan is to run the program as soon as the measurements are taken during a run in order to estimate the velocities and then to decide on the set of observations to make on the next leg. This real-time feedback is

an exciting prospect because it suggests pertinent measurements to make and also enables one to check on the predicted velocities. Preliminary calculations with their data from the past gave velocities that are consistent with their estimates based on other considerations. For these calculations an average estimated value for the mixing coefficient was used. Because of the relative ease of designing a dense observational network and the low cost of a cruise, a group such as Imberger's may be able to collect the data necessary for a field test of the methodology that we are developing. A field program such as CODE may also provide an appropriate data set but so far we have not collected detailed information on that.

More work must be done to extend these results to three-dimensional distributions and to systems in which the mixing coefficients must be treated as unknowns.

A summary of inverse theory has also emerged from our studies. The methodology developed up to spring, 1983, was presented by Veronis at Scripps in April 1983 and will appear in a Springer book in summer 1986. The useful aspects of inverse theory are emphasized and discussions are given for the traps and pitfalls that should be avoided.

An extension of the ONR Grant ($5000) for the period of 1 June to 31 August, 1985) made it possible for Jae Hak Lee to transfer all of the data sets to our own computer and to become familiar with the procedures that were used. During that period we also developed the beginning of a procedure to determine both velocities and mixing coefficients from tracer data. There are serious, unsolved problems in trying to carry out such an

inversion when the mixing coefficients are variable. Work on that problem continues.

An outgrowth of the inverse analyses reported above is an exchange between Wunsch (1985) and Veronis (1986) in JPO. Wunsch's article is basically a set of criticisms of the tracer paper by Fiadeiro and Veronis. Veronis' comments on Wunsch's article will appear in JPO during summer, 1986. My feeling is that this exchange should help in the development of a more reliable methodology for dealing with inverse problems.

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